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Master-slave cluster-based multihop ad-hoc networking

H. Gharavi and K. Ban

A master-slave cluster-based mobile ad-hoc network architecture for multihop communications using the IEEE 802.11 system is presented. The proposed architecture is a mixture of two different types of networks: managed (master-and-slave) and ad-hoc (star). In this architecture, the participating nodes in each cluster communicate with each other via their respective access points (APs), which operate as mobile base stations. A network architecture is presented where APs can be utilised to communicate with other APs in an ad-hoc manner.

Introduction: Motivated by the growing need for multimedia applications such as video, multihop ad-hoc networking is emerging as a viable technology for many applications such as emergency response to natural disasters, bomb threats, search and rescue, clean up operations, etc. In most battlefield scenarios and rescue operations, it is useful to assume that different sets of nodes move as a group. Such an assumption promotes cluster-based network design architectures. The concept of cluster-based networking has been extensively studied in the past several years [1–3]. This concept is based on dynamically selecting a cluster head among the active nodes. The main drawbacks of this approach are the routing complexity as the number of nodes increases, a lack of commercially available hardware, network management, and large overheads that may become a bottleneck in a cluster [3]. Although there has been considerable effort in recent years to improve the routing performance and reduce the overhead, we present a simple, yet easily implementable, cluster-based networking architecture. The architecture utilises existing wireless LAN (WLAN) products and thus can provide wideband access for multimedia communications. In addition, the routing involves only the base of the cluster (e.g. access point), thus reducing the number of ad-hoc nodes in the network.

Network architecture: The main focus has been to develop an experimental setup of the proposed cluster-base network system using WLAN technology. IEEE 802.11 frequency hopping spread spectrum (FHSS) [4] has been selected. FHSS [5] is mainly considered to reduce the interference between the networks, particularly when a large number of clusters have been deployed.

Fig. 1 shows the multihop network architecture that has been designed and implemented for our experimental system. As shown in this Figure, there are two types of nodes in the network, master nodes (MNs) and slave nodes (SNs). The MN which can represent a mobile base station in a cluster operates in a managed network to communicate with its slave nodes within the cluster. Communications among the MNs are performed in an ad-hoc manner. Although an access point (AP) can be used to represent a mobile MN, the main difficulty is that the AP cannot operate in an ad-hoc mode for communicating with other MNs. To overcome this problem, we have designed a simple architecture, which can allow an AP to work in an ad-hoc mode. In this architecture, packets that are received by an AP are routed via a LAN interface to a WLAN card operating in an ad-hoc mode. Therefore, an MN consists of an AP, a LAN interface (e.g. using a laptop or PDA devices), and a WLAN card, whereas an SN uses only a WLAN card (e.g. using PDA). For implementation, each cluster has been assigned to a unique network address (network suffix). For instance, for a network of N clusters, a network address of 192.168.n.0 is allocated to cluster n (Net-n) where $n = 1, 2, \ldots, N$. Under this arrangement SNs in Net-n can use IP addresses between 192.168.n.2 and 192.168.n.244 and 192.168.n.244, while 192.168.n.1 has been allocated to the LAN interface of the MN in cluster n ($MN_{Net\text{-}n}$). In addition, we assigned an IP address of 192.168.0.n to the WLAN interface of the $MN_{Net\text{-}n}$ for ad-hoc networking. Note that all these IP addresses have a subnet mask of 255.255.255.0. Fig. 1 shows a network of three clusters.

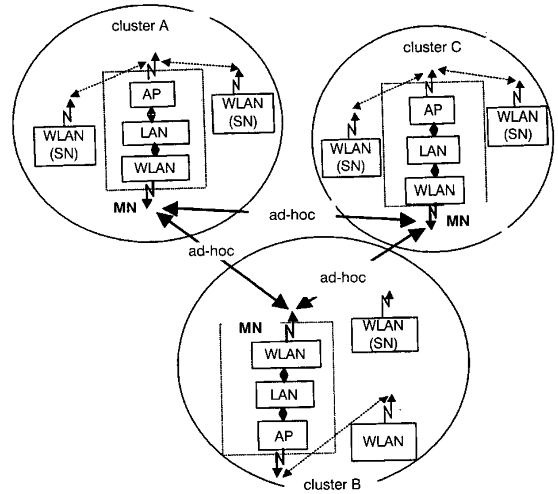

Fig. 1 *Cluster-based multihop ad-hoc network architecture for WLAN*

For ad-hoc routing between the MNs, we have considered the ad-hoc on-demand distance vector (AODV) routing protocol [6]. Thus, AODV has the responsibility of establishing a multihop link from the source cluster to the destination MN. For SN-to-SN communication, this would require encapsulating the IP packet at the transmitting MN with new source and destination addresses that correspond to the WLAN cards of transmitting and receiving MNs, respectively. As soon as the MN receives the encapsulated packet, it will decapsulate and then forward it to the destination SN.

Experimental setup: We have constructed a network consisting of three clusters where each cluster comprises two SN nodes using PDA devices. In our implementation, an MN is composed of an IEEE 802.11 FHSS compliant AP and a laptop PC with an Ethernet port and an IEEE 802.11 FHSS compliant WLAN card. This Ethernet interface is directly connected to the AP through the cross RJ-45 cable. In addition, the data rate for all the IEEE 802.11b FHSS devices has been set to 1 Mbit/s. The operating system for the PDAs and laptop PCs is Linux with kernel version 2.4.x, which can operate as a router to forward IP packets from the AP (the Ethernet port) to the WLAN card, and vice versa.

To avoid roaming, in these experiments we have made sure that all the SNs remain within the coverage area of their associated MN and the clusters are kept sufficiently apart to prevent any overlaps. At the same time, we have prevented the clusters moving too far away from each other, thus allowing the AODV routing to operate without causing link failure too often. These experiments were carried out in an indoor environment. The movement of each MN has been conducted in such a way as to allow a change of AODV routing among the three clusters. We have also made sure that none of the MNs has a line of sight with each other (note that long AC extension cords have been utilised to perform mobility on the APs).

Since this network has been designed for transmission of real-time multimedia information, our main objective has been to evaluate the overall throughput performance of the system utilising the retransmission mechanism that is supported by 802.11. Thus, for each experiment, the number of maximum retransmissions has been set to 0, 1, and 2 on each of the 802.11 devices. We also set the acknowledgment timeout to 8.15 ms. The measurements were carried out many times within several days and the results are shown in Fig. 2. These results demonstrate the effect of the source bandwidth on the overall throughput performance of the network with respect to the maximum retransmission setting. The experiments were carried out using constant transmission rates, where each time the input data stream was generated at differing bit rates. Each bitstream has been packetised with a fixed length of 400 bytes to represent a user datagram protocol (UDP) payload. In addition, the results in Fig. 2 include the scenario where two active SN nodes belonging to the same cluster (source cluster) were involved in sending UDP packets to the nodes in the same destination cluster (both nodes use the same transmission rate). Note that in this network configuration the maximum number of hops that a packet travels is three (e.g. the number of MNs in the network). As can be deduced from Fig. 2, these results simply indicate that for real-time applications such as video, the retransmission may not provide a viable solution, particularly when the source transmission bit rate is relatively high (e.g. higher quality video) or more numbers of active nodes are involved in the contention. An alternative solution would be to apply forward error correction (FEC) codes, instead of retransmission, at the application layer. Unfortunately, existing 802.11 hardware systems discard packets that are corrupted even by a single error.

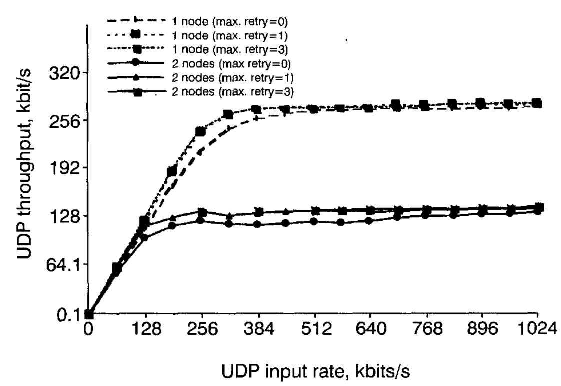

Fig. 2 *UDP throughput rate against source transmission rate*

Finally, in our experiments, we observed that the main limiting factor with expanding the number of MNs is the reliability of ad-hoc routing, particularly in an indoor environment without a line of sight. However, the experimental setup verifies a successful operation of the proposed multihop ad-hoc network. We hope to measure the network performance utilising a larger number of clusters as soon as we receive an appropriate set of battery packs to operate the APs in an outdoor environment.

Conclusion: We have proposed and designed a multihop master-slave cluster-based network architecture. The network is designed using the existing WLAN technology. The network has been successfully implemented and tested under an indoor environment. With future improvement in ad-hoc routing, such a network can be easily expanded to increase the coverage area by using a larger number of clusters.

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Parallelisation of trie-based longest prefix matching for fast IP address lookups

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IP address lookup is an important design issue for the high performance packet forwarding engine. The forwarding engine performs a longest prefix matching on the address lookup for an incoming IP packet to determine the next hop. A parallelisation scheme of longest prefix matching algorithms based on path-compressed trie is proposed. The proposed scheme reduces memory access time of IP address lookup while keeping memory spaces of parallel elements balanced.

Introduction: The increase in hosts and users and the enhancement of service quality causes great increases in Internet traffic. To cope with explosive increases in Internet traffic, the transmission links of networks have been upgraded to multi-gigabit per second speed and this work is progressing rapidly. The packet forwarding process, however, which consists of a forwarding table search and the manipulation of a packet header, lags behind this increasing network speed.

In the IP packet forwarding process, the major performance bottleneck is induced by forwarding table search which is necessary to determine the next hop of every incoming packet on the basis of its destination IP address. This is because the IP forwarding table search performs a longest prefix matching in a classless inter-domain routing (CIDR) environment [1].

Several schemes have been proposed to solve the longest prefix lookup problem. Some of these schemes are implemented on existing routers as a special form of radix trie, called PATRICIA trie [2]. The PATRICIA trie is one of the path-compressed trie, which has no node and has only one child node. However, the PATRICIA trie can degenerate into as many as $O(W^2)$ memory accesses per lookup, where W is the maximum height of the trie equal to the address length, because it may require recursive backtracking during the search. To avoid recursive backtracking on the trie when used in conjunction with prefix matching, dynamic prefix matching has been introduced [3]. The lookup times on such a trie have $O(W)$ memory accesses. Many schemes, as a variation of PATRICIA tries, have been studied for fast IP address lookups [4].

In this Letter, we describe our design of a parallel architecture for longest prefix lookup in order to support fast IP address lookup and we propose a new parallelisation scheme of longest prefix matching algorithms based on path-compressed trie. The proposed scheme reduces memory access time by exploiting inherent path compression owing to parallellisation. Also, the scheme keeps memory spaces of parallel elements balanced by distribution rules.

Parallel architecture: A forwarding engine plays a major role in the IP packet forwarding process, which consists of checking the validity of an incoming packet, searching the outgoing interface from the forwarding table, and manipulating the packet. For an IP address lookup is critical, and several forwarding engines have their own lookup engine which perform a forwarding table search [5].

Fig. 1 shows our parallel architecture on a lookup engine. There are N parallel engines having a controller, a memory, and a selector. The controller performs the search of the entry with the desired key and the addition/deletion of the specific key. Fundamentally, the controller performs the search, addition and deletion operations using trie traversal